CLEEN Consortium Open Session

October 27, 2010

P. M. Niskode'   Program Manage
Rick Stickles   TAPS II Manager
Barry Allmon   Open Rotor Manager
Ross DeJong   FMS/ATM Program Mg

ecomagination℠

imagination at work

GE CLEEN Technologies

1. **Open Rotor**

2. **TAPS II Combustor**

3. **FMS/ATM Integration**

imagination at work

FAA CLEEN Program Goals

	N+1 (2015) CONVENTIONAL CONFIGURATION RELATIVE TO 1998	N+2 (2020-25) UNCONVENTIONAL CONFIGURATION RELATIVE TO 1998	N+3 (2030-35) ADVANCED CONCEPTS RELATIVE TO 2005
NOISE	-32 dB cum below Stage 4	-42 dB cum below Stage 4	-71 dB cum below Stage 4
LTO NOX EMISSIONS (BELOW CAEP 6)	-60%	-75%	better than -75%
AIRCRAFT FUEL BURN	-33%	-50%	better than -70%

Develop and demonstrate (TRL 6-7) certifiable aircraft technology

imagination at work

GE CLEEN Program Goals Timeframe: CY 2010-2015

Open Rotor

- 26% fuel burn reduction (relative to CFM56-7B)
- 17 EPNdB noise reduction (relative to stage 4)

TAPS II Combustor

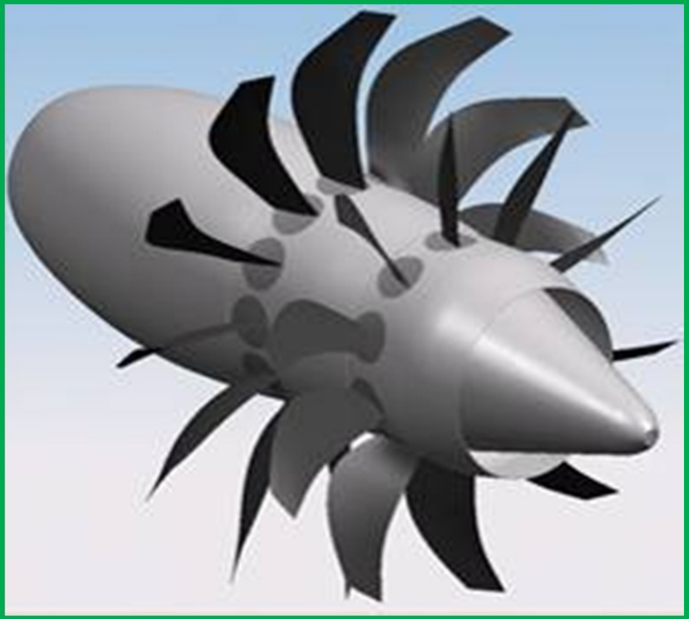
- Emissions 60% below CAEP/6

FMS & ATM

- 7% fuel burn/CO_2 reduction
- 22% landing noise reduction (area of 60 EPNdB footprint)

imagination at work

1. Open Rotor



imagination at work

GE Open Rotor Overview

Goal

- 26% fuel burn reduction (relative to CFM56-7B)
- 15 to 17 EPNdB noise reduction (relative to stage 4)

OR Program has two work elements:

- Blade aero-acoustic assessment and
- Pitch Change Mechanism (PCM) including control system integration

imagination at work

Open Rotor Performance Benefits

Specific Fuel Consumption (SFC):

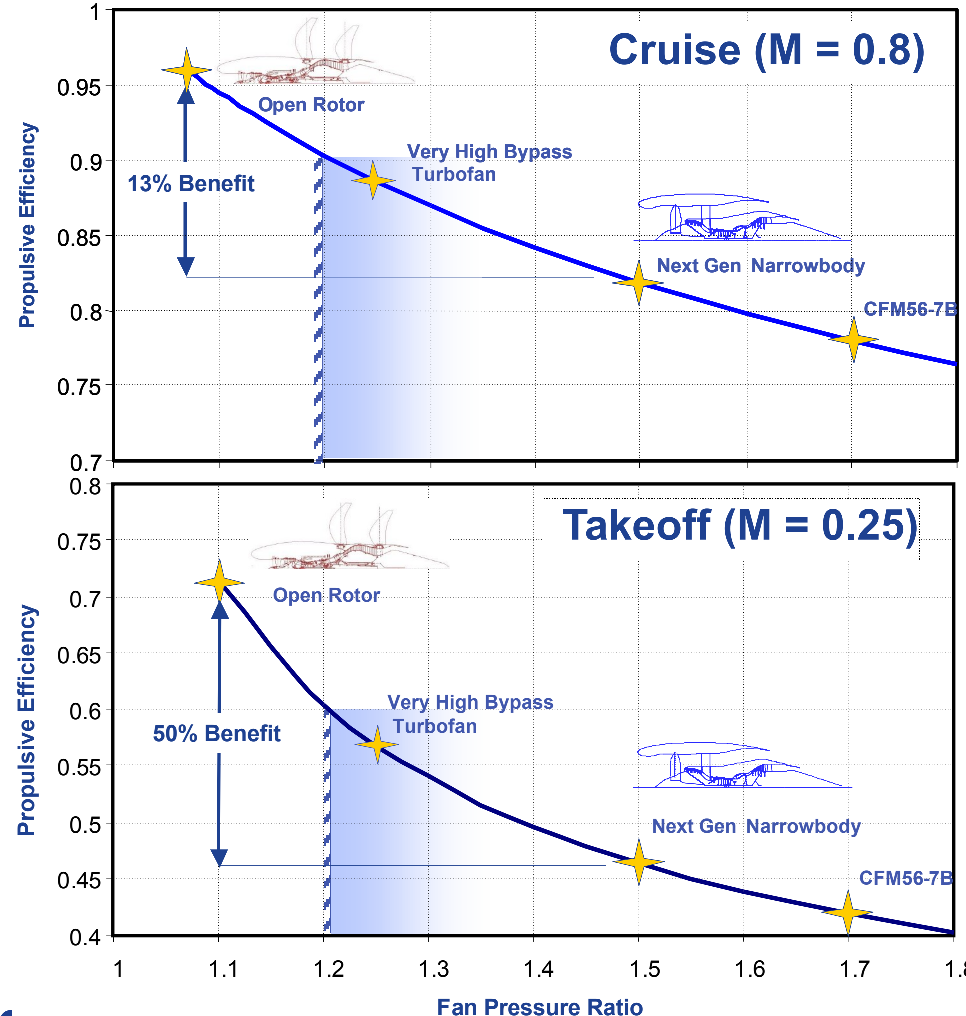
$$SFC \approx \frac{v_0}{\eta_{overall} \cdot FHV} = \frac{v_0}{\eta_{thermal} \cdot \eta_{transfer} \cdot \eta_{propulsive} \cdot FHV}$$

Core

Fan Pressure Ratio

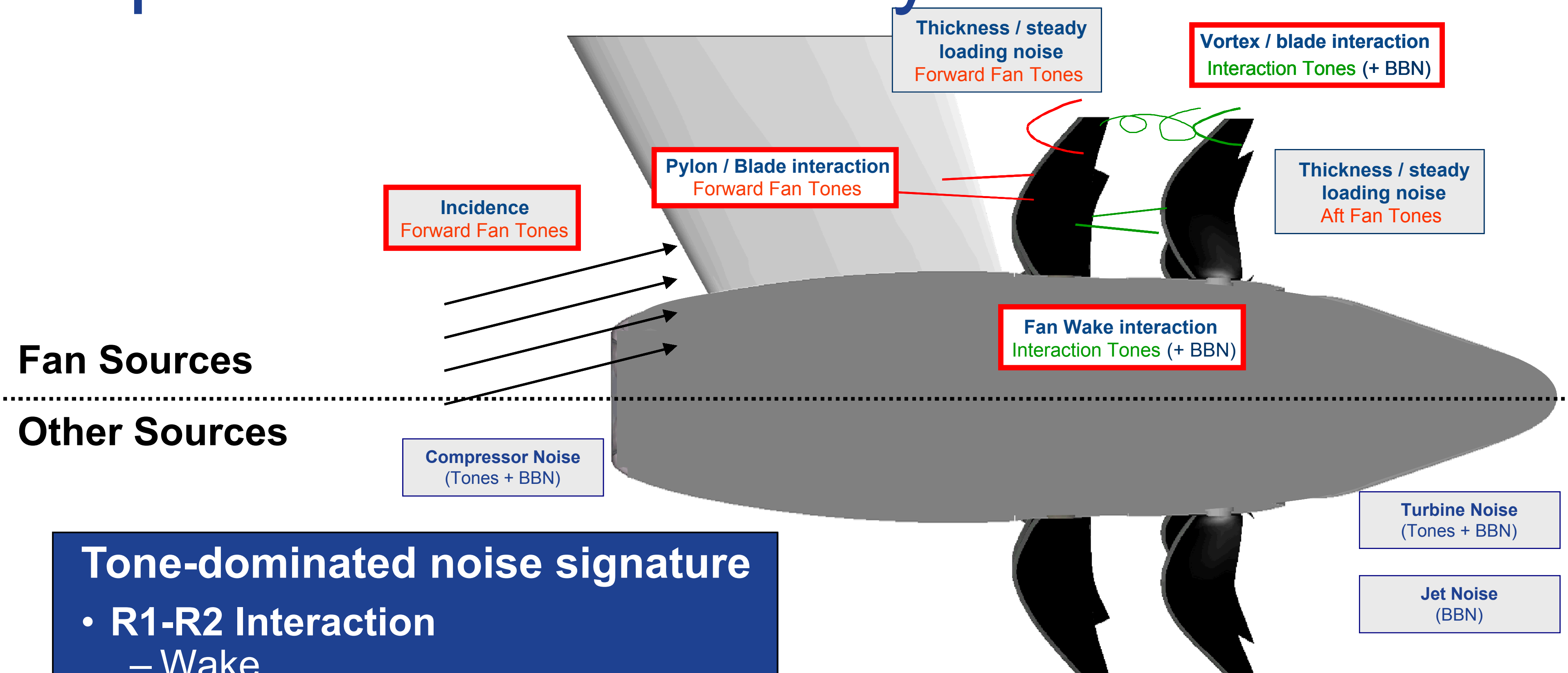
driven by:

- Thermal efficiency: $\eta_{thermal}$
- Transfer efficiency: η_{trans}
- Propulsive efficiency: η_{prop}



Open Rotors provide very high propulsive efficiencies through very low fan pressure ratios

Open Rotor Noise Physics



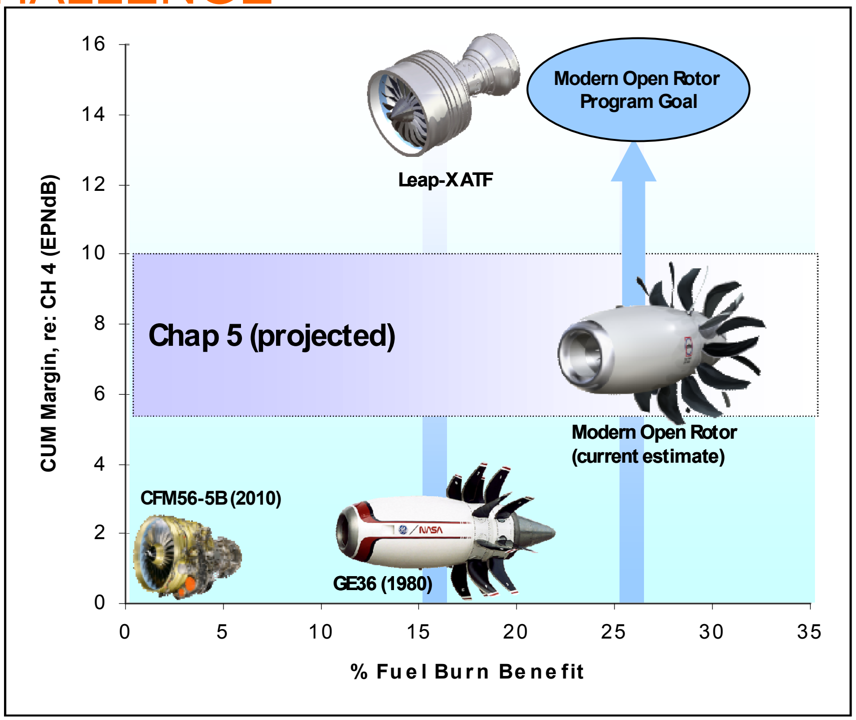
Tone-dominated noise signature

- **R1-R2 Interaction**
  - Wake
  - Vortex
- **Pylon Wake Interaction**
- **Incidence Angle**

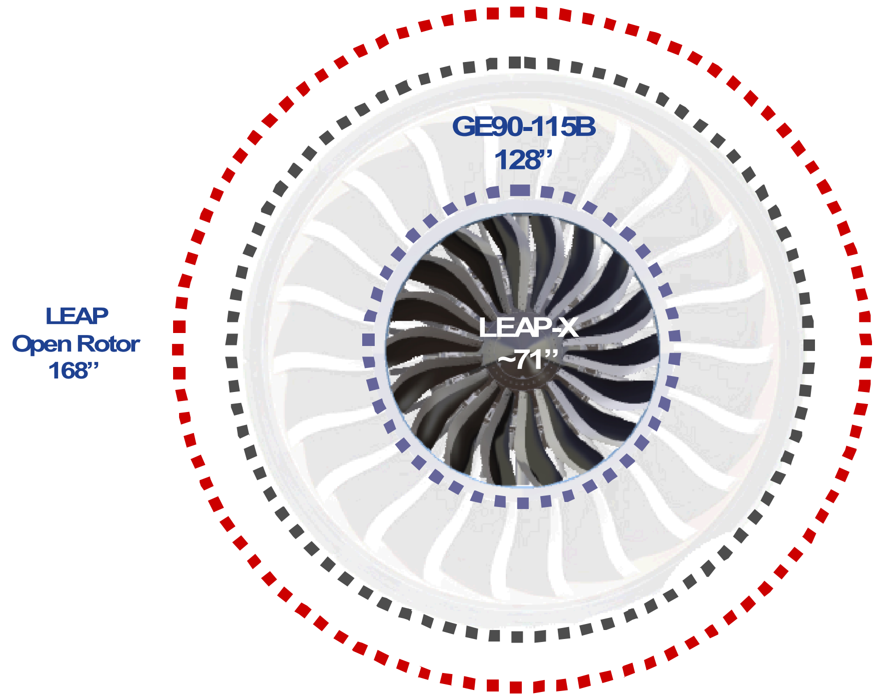
Acoustic design features can reduce efficiency gains

Open Rotor Fan Technology
Key Technical Challenges

FUEL BURN OPPORTUNITY/ NOISE CHALLENGE



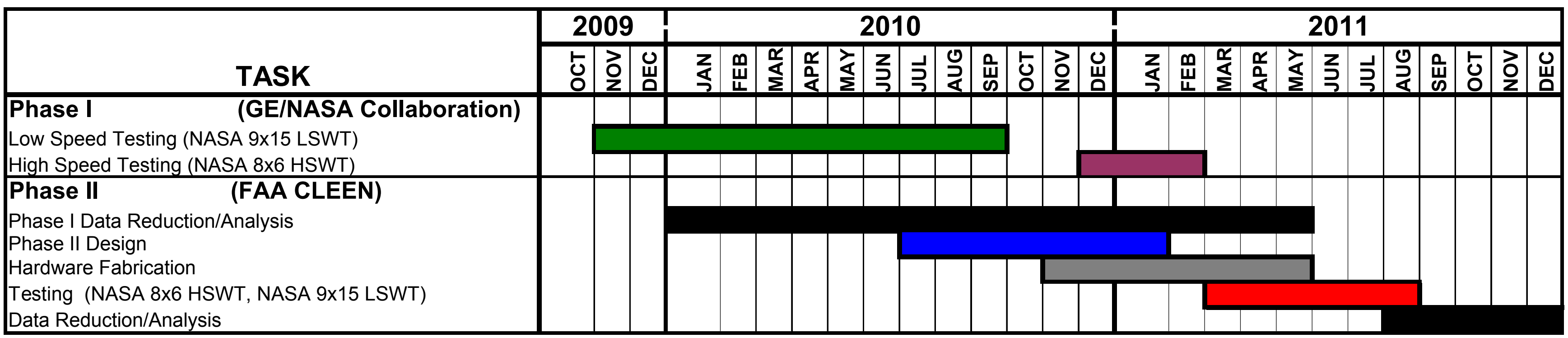
INSTALLATION CHALLENGE



Revolutionary Fuel Burn Advantage … Significant Challenges

Open Rotor Blades Program Plan

- Develop advanced technology blade designs
- Refine designs thru aero-acoustics model tests
- Project blade model data to full-scale application



Phase II FAA CLEEN Effort Builds upon Phase I NASA/GE Effort

Open Rotor PCM System Definition

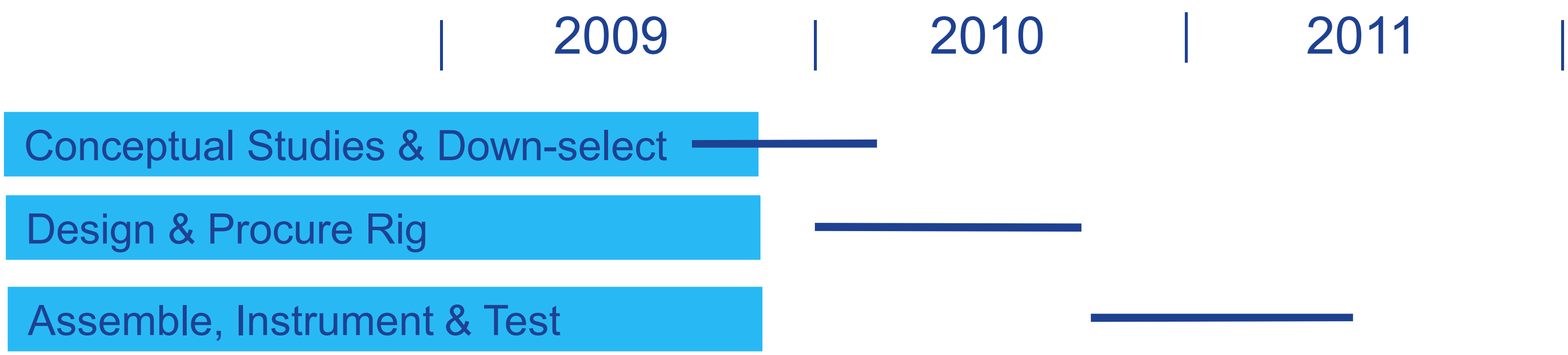
Selected Hydraulic System for Improved Reliability and Weight Savings

Technical Issues and Challenges

- Transfer of fluid from stationary to rotating system
  - Control system responses
- Integration of PCM hydraulics into engine oil system
  - Heat dissipation

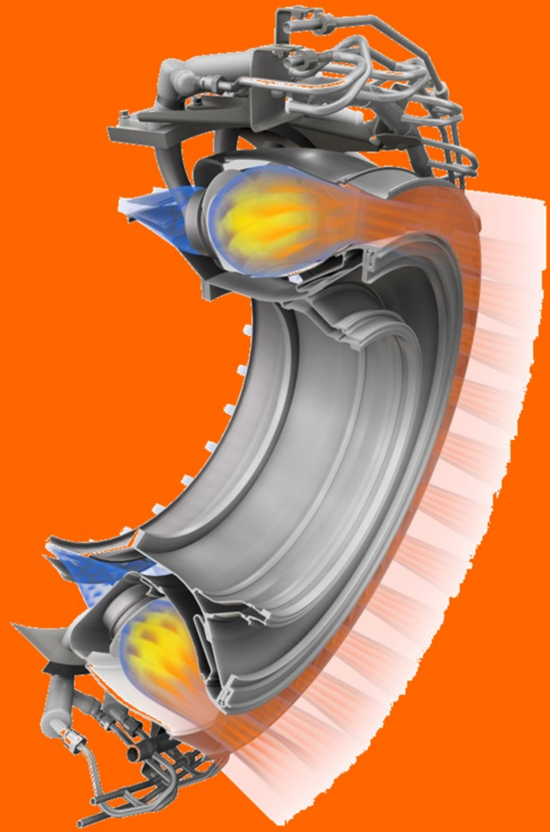
Open Rotor PCM Program Plan

- Validation of hydraulic oil transfer mechanism thru a rig test



- Conduct Thermal Management Studies
  - Develop whole engine thermal model with flight profiles
  - Establish component requirements

2. GE TAPS II Combustor



imagination at work

FAA CLEEN Combustion System Goals

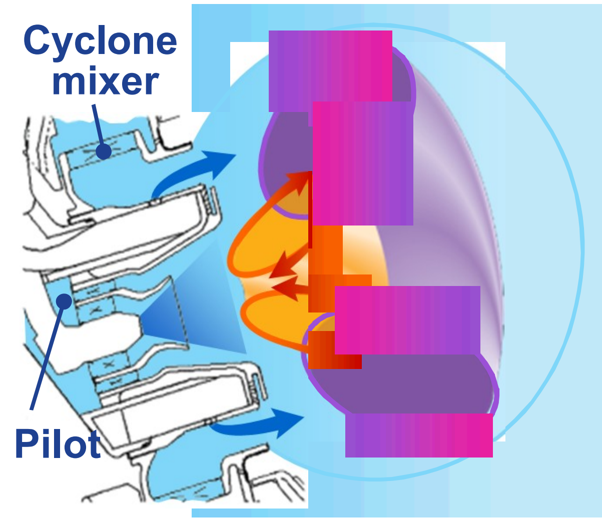
- ✓ LTO NOx emissions …. 60% margin to CAEP/6
- Cruise NOx emissions …. < 9 g/Kg fuel
- Solid Particulate Matter …. 90% margin to CAEP/6 (based on Smoke no.)
- Scale TAPS system …. Narrow body, regional & business jets
  - ✓ FAA CLEEN Goal
  - GEA goal

imagination at work

GE Aviation Approach:
TAPS (Twin annular Premixing Swirler)

Twin annular flames

- Staged combustion within mixer
- Lean-premixed fuel/air mixture in main swirler for reduced NOx at high power
- Central pilot for good operability and low CO/HC at low power
- Greater NOx Reduction at Cruise



Air
Fuel injection
Premixing flame zone
Pilot flame zone

FADEC sets optimum fuel splits

- Balance Emissions, Operability Durability, and Dynamics

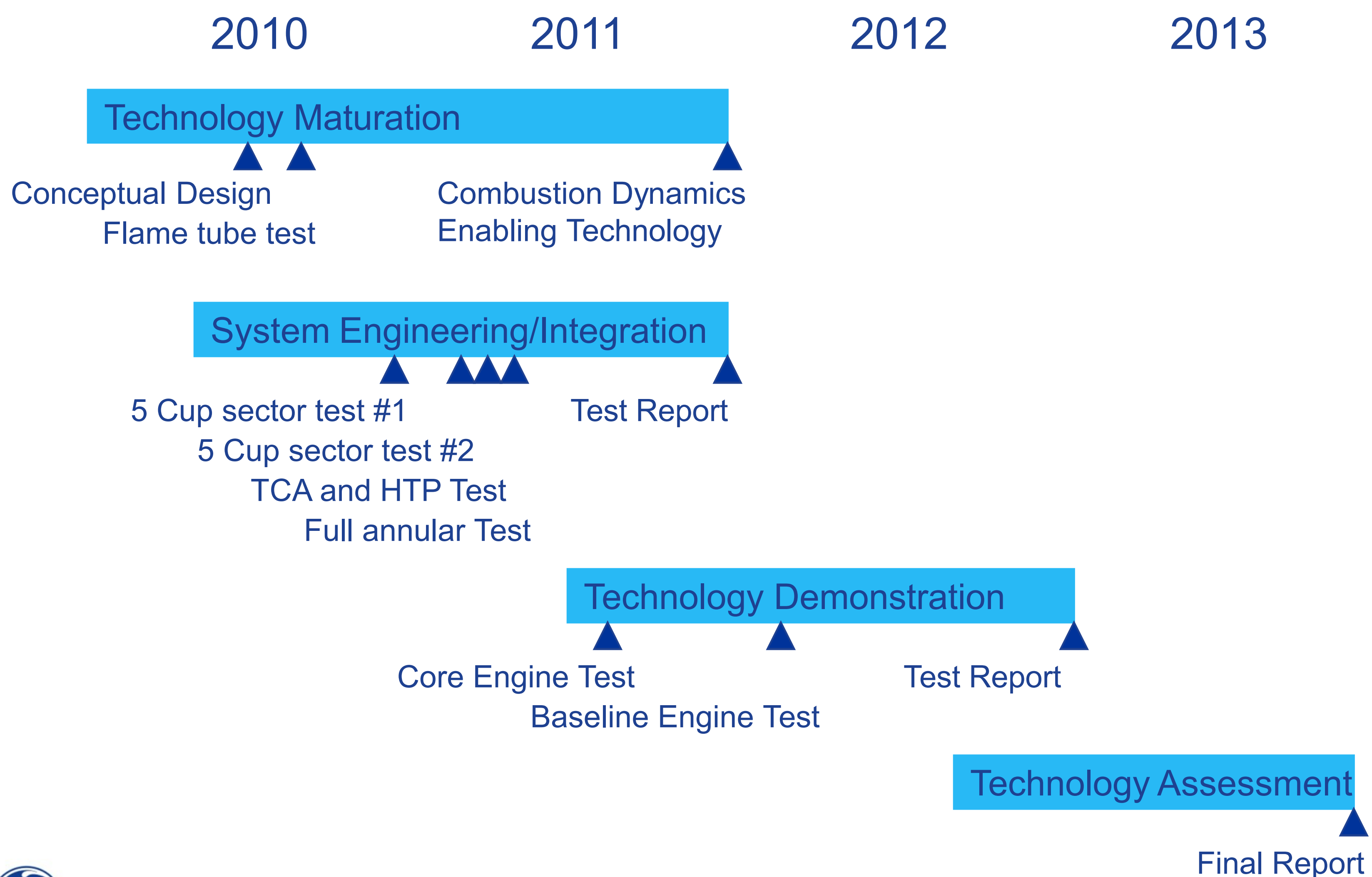
Pilot Only

Pilot + Main

Nozzle sprays shown without air flow (or cyclone mixer)

imagination at work

Combustion System Development



imagination at work

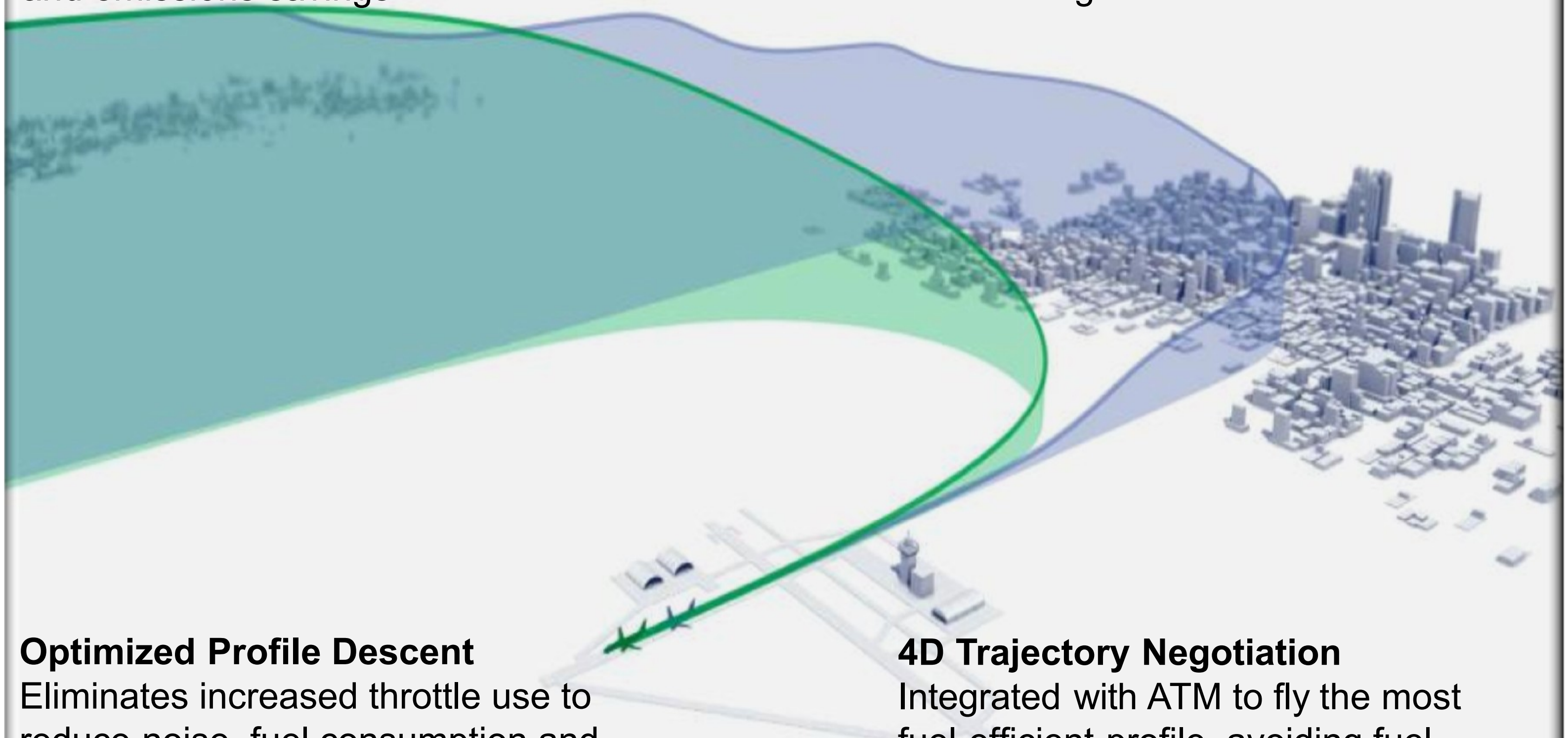
3. FMS/ATM Integration

imagination at work

FMS/ATM Overview

Trajectory Optimization
Improved efficiency throughout the flight - from takeoff to landing - for fuel and emissions savings

4D Trajectory Synchronization
Common view of optimized trajectory to improve predictability and facilitate efficient negotiation



Optimized Profile Descent
Eliminates increased throttle use to reduce noise, fuel consumption and emissions, reducing noise footprint

4D Trajectory Negotiation
Integrated with ATM to fly the most fuel-efficient profile, avoiding fuel-consuming and noisy low-level vectors, improving overall airspace efficiency

FMS/ATM Overview

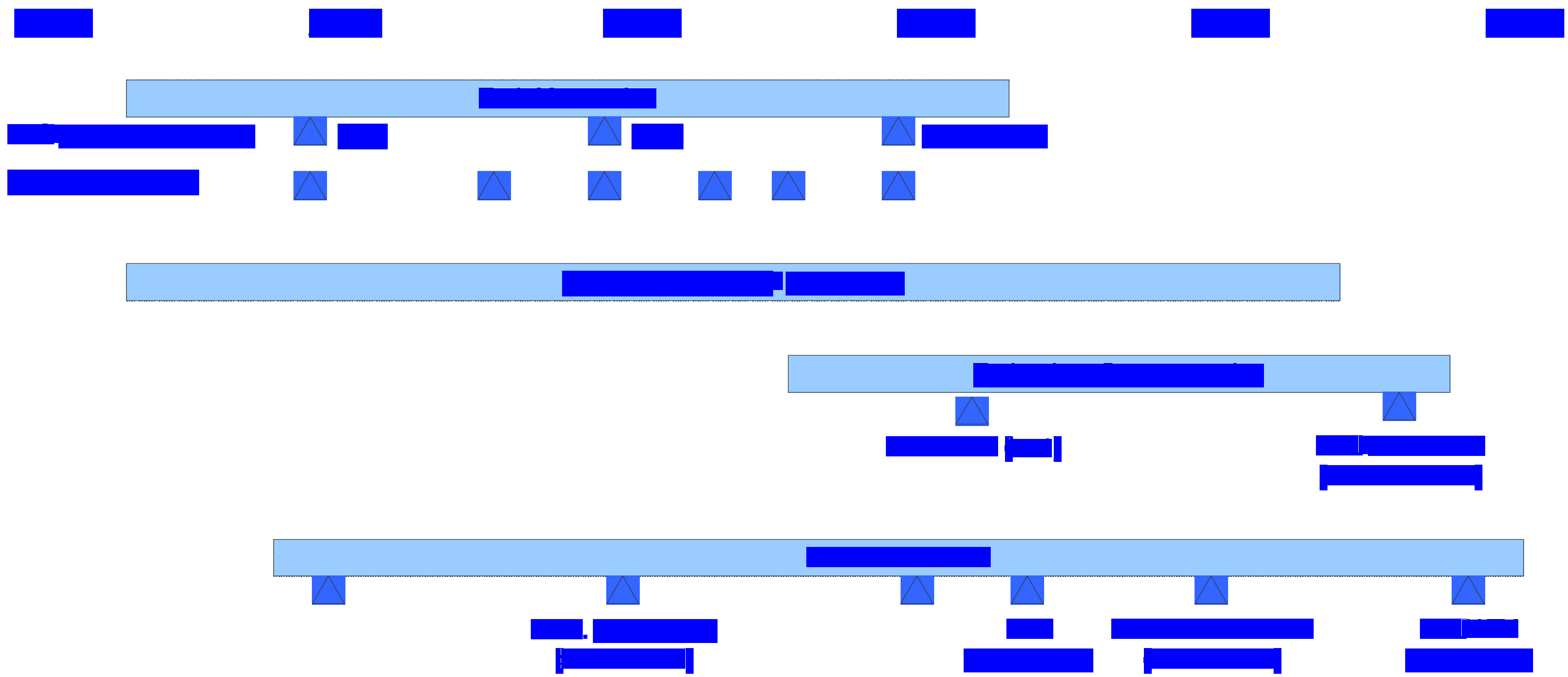
Goals

- Optimize the 4-D trajectory flown by the aircraft throughout flight
- Implement **GE's** FMS technologies to optimize take-off, cruise and landing
- Synchronize trajectories in airborne FMS and **Lockheed Martin's** ERAM
- Utilize **AirDat's** accurate real time weather to reduce fuel consumption
- Demonstrate technologies with **Alaska Airlines**

Key Activities

- Collect baseline data to quantify fuel burn, noise and emissions
- Mature FMS & FMS/ATM technologies
- Determine optimum use of weather
- Develop simulation environment to emulate broad range of scenarios
- Demonstrate technology & validate simulation in 737 shadow-mode trials

FMS/ATM Program Plan



imagination at work

Challenges & Technical Issues

Technology Maturation

- Reaching TRL 6-7 requires significant coordination with FAA
- AEE, ATO-P, ATO-E and Flight Standards

Simulation Environment

- Creation of real time FMS-ERAM simulation environment
- Necessary to model and quantify fuel savings
- Accommodate multiple scenarios & technologies

Weather Benefits

- Numerous weather options and variants of data to analyze

Flight Demonstration

- FMS/ERAM will require shadow mode of live ATC
- Requires considerable planning and FAA coordination

imagination at work

Future Symposium Topics

- Plan/process to feed CLEEN progress back into standardization committees
  - e.g. RTCA SC-214 4D trajectory downlink

imagination at work

imagination at work